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(71) Applicant
Moonstone Designs Limited

(Incorporated in the United Kingdom)

Brentford Station House, Boston Manor Road, Brentford, Middlesex, TW8 8DT, United Kingdom

(72) Inventor
Thomas William Bach

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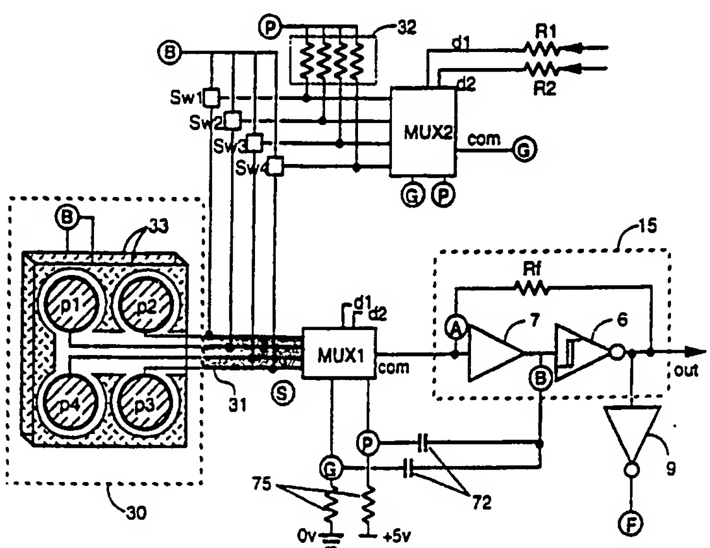
(74) Agent and/or Address for Service
Baron & Warren
18 South End, Kensington, London, W8 5BU, United Kingdom

(54) **Device for determining the presence and/or characteristics of an object or a substance**

(57) An imaging device whereby the internal characteristics and/or external dimensions and/or location of an object are determined by one or more sensors (p1-p4) and optionally one or more slave members which may be driven in or out of phase to the sensors and which transmit an effect to the sensors directly and via the object to be characterised. The sensors (p1-p4) vary the frequency or amplitude of an oscillator (15) which contains a buffer/follower amplifier (7) and a Schmitt trigger (6). The slave members are typically driven via an inverter (9). Unused sensor lines are buffered via buffered switches (Sw1-Sw4). Connecting lines to a plurality of sensors or slave members pass through multiplexers (e.g. MUXI) with buffered power rails (P, G) in order to eliminate the internal capacitance to the voltage supply and ground rails.



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(71) Applicant (*for all designated States except US*): MOONSTONE DESIGNS LIMITED [GB/GB]; Southbank House, Black Prince Road, London SE1 7SJ (GB).

(72) Inventor; and
(75) Inventor/Applicant (*for US only*) : BACH, Thomas, William [US/GB]; 47 Rugby Road, Brighton, East Sussex BN1 6EB (GB).

(74) Agents: MURGATROYD, Susan, Elizabeth et al.; Baron & Warren, 18 South End, Kensington, London W8 5BU (GB).

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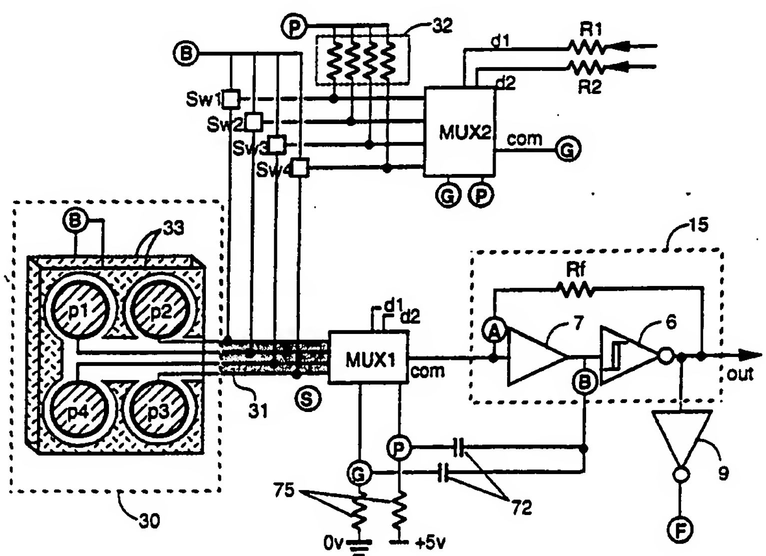

(57) Abstract

An imaging device whereby the internal characteristics and/or external dimensions and/or location of an object are determined by one or more sensors (p1-p4) and optionally one or more slave members which may be driven in or out of phase to the sensors and which transmit an effect to the sensors directly and via the object to be characterised. The sensors (p1-p4) vary the frequency or amplitude of an oscillator (15) which contains a buffer/follower amplifier (7) and a Schmitt trigger (6). The slave members are typically driven via an inverter (9). Unused sensor lines are buffered via buffered switches (Sw1-Sw4). Connecting lines to a plurality of sensors or slave members pass through multiplexers (e.g. MUX1) with buffered power rails (P, G) in order to eliminate the internal capacitance to the voltage supply and ground rails.

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DEVICE FOR DETERMINING THE PRESENCE AND/OR CHARACTERISTICS OF AN OBJECT OR A SUBSTANCE

This invention relates to a device for determining the presence and/or characteristics of an object or a substance.

Common ways of determining the position, size, shape and internal characteristics of an object are optical, inductive, ultrasound and capacitive. Sample uses for this are coin discriminators, quality control, industrial process control, and medical imaging. Inductive systems only tend to work well with metal objects and also tend to be temperature dependent. Additionally they cannot be made small enough to have very fine resolution. Optical systems are subject to interference by dirt and are frequently fragile, requiring exposed transparent lenses. Non-raster optical systems require good geometric matching of the sender receiver diodes to attain reliable and accurate imaging. Capacitive systems on the other hand are robust, cheap, can be made very small and low power, and do not require great mechanical precision to work well.

Conventional capacitive sensors, such as those used in keypads or industrial proximity sensors, either require separate electronics for each sensor pad, or give reduced sensitivity due to parasitic capacitance effects in the multiplexer used to switch each pad to the sensing electronics. Many existing systems operate with a tuned circuit driving each pad and detect the amplitude loss when this circuit is de-tuned by an object proximate to the pad. This circuit is very difficult to design so that pad variations (due to differences in geometry, or external influences such as dirt or moisture) can be automatically compensated for. This is because the tuned circuit would need to be re-tuned for each pad to keep the same sensitivity.

Other systems use a transmit / receive technique based on an x/y matrix. The presence of an object couples a vertically scanned line to a horizontal one. These systems suffer from an inherent theoretical lack of sensitivity, and also from noise pick-up, as most of the receiver area is not covered by the sensed object. Similarly x/y methods where a single tuned circuit is applied by a multiplexer to horizontal and vertical lines (looking for the crossing point where a vertical and horizontal lines were touched) lacks inherent maximum sensitivity possible given the area of the sensing pad.

It is an object of the present invention to provide an improved device for determining the presence and/or characteristics of an object or a substance, which device alleviates the aforementioned problems associated with such known devices and is capable of giving greater control over the shape of induced electric fields.

According to one aspect of the present invention, there is provided a device for determining the presence and/or characteristics of an object or a substance, said device comprising capacitive means, the capacitance of which is changed due to the presence and/or characteristics of said object or substance, and a circuit arrangement for detecting said change in capacitance, characterised in that said capacitive means comprises one or more sensors and one or more slave members positioned relative to said sensor or sensors and arranged to be driven in a predetermined phase relationship with respect thereto, such that the change in capacitance detected by said circuit arrangement is influenced by electrostatic coupling between said one or more sensors and said one or more slave members.

By this arrangement the characteristics of the object can

be determined by analysing the responses from the one or more sensors. By using slave members, the sensor or sensors will be affected by the degree of electrostatic coupling between the one or more slave members and the one or more sensors. Buffering means may be used to enhance the sensitivity of the device and to shield the sensors from unwanted external effects.

The invention thus makes use of capacitive means to characterise an object or substance by use of one or more slave members, preferably in the form of specially shaped pads or plates, that drive the material of the object or substance capacitively and couple to a sensor which is also preferably a pad or plate. These shaped plates may form a physical matched filter. The short, medium and long range effects of these plates can be exploited. The device, in accordance with the invention, may be used to characterise an object of any material or of a substance such as a particular chemical.

It has been discovered that the invention can be used to create a new effect which is the effective grounding out of this capacitive coupling effect by objects at a far distance. This allows the presence of objects or substance to be sensed at an order of magnitude greater distance than previously possible and its characteristics determined dielectrically.

The or each sensor is suitably driven by an oscillator of the detection circuit, the sensor response being measured either by a change in frequency or by a change in amplitude of the output of the oscillator. Preferably the oscillator circuit contains a Schmitt trigger. The device may include means for storing the response of the or each sensor singly and when the or each slave member is addressed, thus building up a characteristic pattern of values. This stored

information may be used in conjunction with pattern matching, algorithmic processing, or simple switching of sensors or slave members looking for effects above or below a threshold.

When the sensor determines the frequency of the oscillator, the frequency is affected by which sensor and which slave member is addressed. The frequency output is typically an analogue reflection of the object characteristics. Slave members may be driven in or out of phase with respect to the sensor with the same or a different waveform to the sensor, but generally a square wave. The frequency of the oscillator is affected by coupling of the currently selected sensor to one or more slave members, either directly or via the object being sensed.

Measurement by change in amplitude is suitable for certain, particularly long range, applications. In this arrangement, it is desirable to use a slave member which is internally frequency locked by the use of, for example, a ceramic resonator. In this instance the sensor is constructed to 'track' this frequency by the use of a Phase-locked loop (PLL). Synchronous amplitude demodulation of the signal received gives an extremely noise-immune system, but at a higher cost than the frequency variant system more commonly used.

Further noise reduction effects can be obtained by using a square wave to drive a slave member and in the receiver section only sensing the effect during a narrow time window around the square wave transitions. This can be implemented by measuring the slope of the oscillator triangle wave during the window.

Accordingly, in another aspect of the present invention there is provided a device for determining the presence

and/or characteristics of an object or a substance, said device comprising capacitive means, the capacitance of which is changed due to the presence and/or characteristics of said object or substance, and a circuit arrangement for detecting said change in capacitance, characterised in that said circuit arrangement includes a fixed frequency oscillator, the amplitude output and/or phase of which is dependent on said change in capacitance.

According to yet another aspect of the invention, there is provided a device for determining presence and/or characteristics of an object or a substance, said device comprising capacitive means, the capacitance of which is changed due to the presence and/or characteristics of said object or substance, and a circuit arrangement for detecting said change in capacitance, characterised in that said capacitive means includes a plurality of sensors connected to the circuit arrangement via one or more multiplexers the power rails of which are connected to buffering means so as to inhibit internal capacitance to said rails.

In a preferred arrangement, the buffering means includes a voltage follower connected to the power rails via capacitors. Unaddressed lines and sensors may be connected to the voltage follower by extra switches, thus eliminating the feed through capacitance effects in individual switches in the or each multiplexer and allowing long lines to the sensors on the same side of the PCB upon which the device is mounted. The on/off ratio of these extra switches can be improved by novel means in the form of an additional impedance element from each sensor to the output of the voltage follower.

In addition to buffering the multiplexer, the back-plane may also be connected to the buffering means, so that not only is the sensitivity increased but also the device can

be made very thin with connectors or electronics to one side. This allows a three dimensional or flexible design to be made. The buffering means have good radio frequency rejection properties being so near the sensing pads. The electronics driving the buffering means are band-pass in nature to increase this rejection and to cut down on spurious emissions.

In a preferred arrangement, the output of the or each multiplexer is fed to the voltage follower which has its power supply rails driven by a later stage low output impedance voltage follower. The voltage follower may include a dual-gate Mosfet and gate 2 of the Mosfet is suitably connected to a buffered point for optimal elimination of the input capacitance.

The device preferably includes means for measuring the effective charge rate or loss tangent from the or each sensor, which is dependent on the object and which if any slave member is addressed. This can be measured indirectly by having this effect control the oscillator.

In a specific arrangement, the internal characteristics and external dimensions of an object are determined by passing the object through a channel past the one or more sensors and slave members which are shaped to provide optimum identification of the object. The sensors and slave members may be separated electrically by extra sections located between them on a PCB and in the wiring to the PCB. The extra sections are driven by the voltage follower. The sensors and slave members may be etched onto one side of a double sided PCB, with one or more sensors and/or slave members being located opposite, typically detecting the thickness of the object. The outer faces of the PCB(s) are connected to the voltage follower thus isolating the sensing system from external effects especially RFI.

One preferred embodiment comprises a single sensor and concentrically arranged buffer members and slave members. The slave members are driven via a multiplexer. The sensor may be circular and the buffer members and slave members may be shaped to form arcs of circles matching that of expected circular shaped objects. This arrangement can then determine the number of objects present as well as their diameter, surface area, surface roughness and thickness. Alternatively the sensor may be square or otherwise shaped and the buffer members and slave members may have corresponding corners and straight sides extending around two, three or all sides of the sensor.

The device may be arranged such that the characteristics of an object can be determined whilst the object is moving or rolling and/or while it is stationary.

In one particular embodiment, the object is held stationary behind a solenoid controlled gate for recognition by the device and is released and redirected to a further solenoid gate or by 'pulsing' the first gate. This embodiment is suitable when the objects to be measured are coins or tokens in a vending machine. In this arrangement, the total coin detect mechanism can be made only slightly thicker than the coin detected. All electronic components can be located off-board. The circuitry is less expensive and less susceptible to temperature effects than non-capacitive systems. Additionally, it works with coins of non metallic nature, and it can be cheaply upgraded to much higher degrees of discrimination by simply adding more or smaller slave members. This allows more highly specified items to be used i.e. value tokens or security/identification tokens to be used in once only or highly secure applications.

The device, in accordance with the present invention, may be used in many different applications. Examples of such applications are as follows:-

(i) to determine the two or three-dimensional shape of an object by virtue of a characteristic pattern of responses caused by the varying proximity of an object to each sensor or slave member;

(ii) to determine the pressure profile of an object, using a compressible membrane on top of an array of sensors;

(iii) internal scanning of objects to detect impurities or to remotely measure the dimensions of encapsulated objects;

(iv) for body surface imaging in medical applications such as retina contour mapping or joint measurement;

(v) as a vandal resistant or 'Through-Glass' keypad;

(vi) as part of a "pattern recognition" system utilising the responses of the various sensors;

(vii) for non invasive chemical dielectric testing;

(viii) for capacitive sensing at a distance from a VDU or LCD screen (i.e. as a 'touch-screen');

(ix) to read the dielectric characteristics embedded in an identity card;

(x) in much larger scale / longer range detection - for example to make a collision avoidance device for vehicles.

In this specification, the term 'Slave' is intended to cover any mechanism for transmitting an electrostatic signal to a sensor. Such devices are generally oscillating in a synchronous manner to the sensor in a predetermined phase relationship. They may be autonomous or directly controlled by an oscillator in the sensor.

The term 'capacitance' as used in this context is that

property which is measured by the effective charge rate or loss tangent of a sensor. This is most generally the complex impedance of an object which is normally primarily determined by the object's dielectric characteristics.

Additionally, a device or point which is 'buffered' is one which is connected, directly or indirectly, to the output of a voltage follower/buffer amplifier whose input is generally, directly or indirectly, connected to a sensor plate.

'Buffering means' generally consist of one or more voltage followers connected to other components or plates.

The invention will now be described by way of examples with reference to the accompanying drawings, in which:-
Figures 1 and 2 show respectively schematic elevational and sectional views of one embodiment of the present invention;
Figure 3 shows schematically a circuit layout of the embodiment in Figures 1 and 2;
Figure 4 shows a schematic layout of the part of the circuit shown in Figure 3;
Figure 5 shows a schematic layout of another embodiment in accordance with the present invention,
Figure 6 shows one application of the embodiment shown in Figure 5;
Figures 7a and 7b show diagrammatically the medium range effect of the present invention and the equivalent capacitive network, respectively;
Figures 8a and 8b show diagrammatically the long range effect of the present invention and the equivalent capacitive network, respectively;
Figure 9 shows the approximate long range detection effect lines of another embodiment, iso-potential lines being perpendicular to these detection effect lines;

Figures 10 and 11 show two possible arrangements of sensor arrays for use in three-dimensional surface or internal imaging;
Figure 12 shows a cross - section of field lines of a sensor array such as that in Fig. 10 or 11 when a curved object is nearby;
Figures 13 and 14 show schematically two alternative modified circuit arrangements of a device in accordance with the invention;
Figure 15 shows schematically a circuit arrangement in accordance with another embodiment;
Figure 16 shows a plan view of an object being characterised by a sensor array;
Figure 17 shows schematically another embodiment particularly for coin/token sensing;
Figure 18 shows schematically a further embodiment wherein queuing of coins/tokens is permitted;
Figure 19 shows schematically yet another embodiment for sensing of rolling coins/tokens;
Figure 20 shows graphically a simplified statistical output of the embodiments shown in Figures 14, 15 and 16;
Figures 21 & 22 show schematically the physical layouts of two alternative embodiments suitable for chemical sensing;
Figure 23 shows a circuit arrangement of yet another embodiment of the invention; and
Figures 24 shows a technique for enhancing internal imaging.

Referring firstly to the embodiment shown in Figs. 1 to 3, a sensor plate 1 typically controlling the oscillation frequency of an oscillator 15 containing a CMOS Schmitt trigger 6 is buffered first by a low offset, low output impedance voltage 7 which drives a buffer plate 2 and a back shield plate 5. Slave members in the form of specially shaped slave pads or plates 3a, 3b, 3c are switched to a point (F) in the circuit to cause the frequency of oscilla-

tion to change, usually decreasing, by coupling through the air to the sensor plate 1. A switch 8 may be included to cause the slave pads to be driven in phase (I), or out of phase (O) via an inverter 9, and the slave pads are selectively addressed via a multiplexer 10 controlled by microprocessor 14 and selective address and inhibit lines 16.

The voltage follower 7 is shown in detail in Figure 4. The voltage follower is designed to have a negligible input capacitance by buffering the drain D of a dual gate Mosfet Q1 and the power supply lines of the first stages, and for best use a dual-gate Mosfet is used with an Ft of several GHz. The source of this Mosfet Q, drives another high speed follower stage composed of an npn transistor T_1 and a pnp transistor T_2 with a current source C. These circuits are designed for low capacitance at every internal node and the PCB is laid out so the buffer lines drive the smallest external capacitance to other lines on the board. Figure 4 also shows an optional potential divider circuit 19 which provides a means to vary the fixed hysteresis level of the Schmitt trigger 6 thus decreasing the frequency and reducing the effect of noise pulses.

As seen in Figure 2, as an object 16 moving down a track 13 overlaps the slave pads 3a, 3b, 3c and the sensor 2 simultaneously on the X axis it will couple more of the field to the sensor and thus the frequency will change. This change will be less if the object is further away from the sensor on the Z-axis, has a smaller dielectric constant, or is smaller or of a different shape than the selected slave pad. As each slave pad is addressed the change in oscillation frequency is stored in the microprocessor 14, so as to build up a pattern indicative of the characteristics of the object 16.

The pads or plates 1, 2, 3a, 3b, 3c are etched on the same

double sided PCB 4. The object has an external capacitance to ground and as the circuit will have some connection to ground albeit only capacitive, this can affect the measurements.

The object is touching or almost touching the sensor/slave pad arrangement, the capacitance to ground will be small and can be made negligible by enclosing the object at this point in a box 18 whose walls consist of shield plates driven by the voltage follower. Plate 5 forms one wall of this box. The box can then be lined with further slave pads (on the inside of the other walls) shaped to characterise the object spatially in three dimensions. Most usefully the thickness can be determined with a slave pad 17 opposite and parallel to the sensor. Extra sensors or slave pads can be added to the left of this sensor/slave pad arrangement to deal with the case of many objects on the same track.

For thickness detection, a circular slave pad 17 (Figure 2) located opposite the coin is turned on and driven in/out of phase. On going out of phase the frequency of oscillation decreases in proportion to the distance from the slave pad 17 to the top surface of the coin. The slave pad which is measuring thickness is made physically smaller than any coin expected and smaller than the sensor plate 1. This is to allow an effect that is mainly due to thickness of the coin coupling the slave pad 17 to the sensor 1 rather than its diameter.

Figure 5 illustrates the layout of a device in accordance with another embodiment of the invention having a sensor arrangement 30 comprising four sensor pads p1-p4. The pads p1-p4 are connected to multiplexers MUX1 and MUX2 via lines 31 on the same layer of PCB. The sensor pad to be addressed is selected by data lines (d1,d2). Both multiplex-

ers have power supply lines (P) and (G) which are buffered by connection to the output of voltage follower 7 at buffer point (B) via capacitors C1, C2. The multiplexers are addressed by means of resistors (R1,R2) which are large enough to ensure that the protection diodes inherent in the multiplexers are not turned on and thyristor action does not commence. Optionally the sensitivity is enhanced by elimination of feed-through capacitance (approximately 0.25 pF for each multiplexer switch) by connecting unused pads to the buffer point (B). This is effected by the group of switches (Sw1 - Sw4) whose power supply lines themselves are buffered. This prevents non-selected pads from affecting the frequency of oscillation when touched. If slave members are used, they are connected via inverter 9, to, for example point (F) in the circuit of Figure 5.

The device makes maximum use of buffer/follower techniques so that the multiplexer arrangement, having its power lines and unused input lines buffered, is transparent electrically. This is accomplished by the buffering of the power lines to multiplexer MUX1 which cancels the capacitance (approximately 4 pF) of each analogue input pin to the rails and the combined capacitance (i.e. approximate number of analogue switches multiplied by 4pF) at the common pin. The unused input lines are connected to the buffer point (B) through multiplexer MUX2, the rails of which are also buffered for capacitance cancellation. This has the effect of cancelling the feedthrough capacitance of multiplexer MUX1. The feedthrough capacitance of the switches SW1-SW4 is cancelled by having them addressed and pulled to the buffer by means of one of resistors 32. The switches themselves have buffered rails which cuts down on parasitic capacitance from the switches to the rails and allows the tracking of lines to or from the switches to be near the sensors.

The first stage of the oscillator 15 is designed to have an extremely low input capacitance so that any capacitive temperature effects at this point are made negligibly. This also allows smaller sensor pads to be used which means less noise is picked up. These very small pads still have high sensitivity due to a focussing effect and shielding from background capacitance caused by a common shield plate 33 also connected to the buffer point (B) and located behind all the pads and around each pad (p1-p4).

Because only one oscillator arrangement is required, a high investment can be made in it. The device is therefore sufficiently sensitive and stable that it can be used for multi-pad dielectric sensing of chemicals, for example in routine blood analysis. It is also so sensitive that single sided PCB technology can be used with resultant costs saving due to the lack of plated-through holes and the potential use of carbon film/membrane board techniques. This also can result in a much thinner design.

Figures 6a and 6b illustrate one of many possible uses of the embodiment described in Figure 5 as a 'through-glass' keypad for public access information systems. The whole device is mounted on the inside of a plate glass window 40. The first 'layer' is typically legends and artwork on a sticker 43 visible through the glass indicating key positioning and giving basic operating instructions. Bonded to the back of this is the main sensor PCB 30, which is double sided, consisting of the sensor pads (p1-p4 etc), layer 44 and the shield layer 33 as shown in Figure 5. This is connected to a separate PCB 42 containing the electronics and providing a computer interface and connection 43 - typically keyboard emulation or RS232. The electronics are sealed and protected in a cover 41 which is typically moulded ABS.

Substantially the same embodiment can be used as a 'through-book' sensor, or as a vandal resistant keypad for e.g. door entry systems on blocks of flats. The main variation is the material in front of the sensors, which can be anything conductive, but is paper in the first instance and typically a thick layer of polycarbonate in the second instance above.

As shown in Figs. 7 and 8, as well as the short range effects described so far, the device is also sensitive to medium range and long range effects.

In thé medium range case shown in Figure 7 with an object 35 at a distance of approximately the sensor's shortest dimension away, the effect of the slave on the sensor will be affected both by the capacitance from the object to sensor (Cs) and to slave pads (Cf) and also by the object's capacitance to ground (Cg) which causes a potential divider 36 to be set up as shown. This capacitance is of the same order of magnitude as the capacitance to the plates on the sensor board - i.e. $Cg \approx Cs \approx Cf$.

In the long range case shown in Figure 8, the capacitance to ground is so large that the object 35 is hardly driven at all by the capacitance Cs to the slave pad (F) and thus the object 35 is not relaying much of this effect to the sensor. This can be exploited for greater range by making the slave pad to sensor distance much greater (of the order of ten times the sensor's greatest diameter). Typically without an object in the field, the sensor's frequency is changed by only a few percent by action of the slave pad via the linkage capacitance (Cl). This change will be diminished significantly by the aforementioned capacitive potentiometer effect when an object is at a range of approximately the sensor to slave pad distance. The effect is that of the field 40, as shown in Figure 9, being par-

tially absorbed. In practice this means having separate sensor and slave pad boards placed at a distance apart on the X axis at an equal distance to the required distance to sense presence along the Z axis. The in/out of phase inverter can be of any waveshape as long as it increases or decreases the frequency of the sensor.

The amplitude of the waveshape in the slave pad should be increased by using higher voltage supply rails until a suitable signal to noise ratio is observed, generally at least one percent change in frequency between the slave pad being active and inactive. For best long range determination, the slave pads are switched in and out of phase at a repetitive rate and correlation and synchronous demodulation methods are used to determine the presence and exact location of an object. The distance at which this "far" field effect happens can also be changed by either providing an earthed plane near the object or another plate driven by an out of phase signal with respect to the sensor with an adjustable amplitude. This signal can be a square wave whose switching points are at the peaks of the triangle wave generated by the oscillator 15.

This effect can also be utilised in materials where, instead of air being the dielectric, a low dielectric medium is used and for the "object" a relatively high dielectric mass is located inside the material. The high dielectric mass will be earthed if it is actually in the soil; or similarly if the mass on the further side has a large capacitive coupling to earth; or if an earthing plate is arranged on the back of the "object" to provide this; or if a "super earth" effect is generated by driving a slave plate on this back with a signal out of phase with the sensor. This signal can then be made greater or smaller which will move the long range effect toward or away from the sensor. This enables materials to be looked into and

the internal characteristics determined further. This should be combined with known effects of placing slave pads at different distances from the sensor for internal throwing of the field.

Another embodiment uses the system for a collision avoidance device for automobiles. It uses two pads as in figure 9. This uses primarily the long and medium range effects described above. One of the two pads is used as a sensor, the other as a slave, which may be driven in or out of phase, with or without amplification. Possibly, the two pads can alternate as sensors and slaves to monitor any near field effects, which would differentially affect the pads according to object distance on both the X and Z axes.

Figs. 10 and 11 illustrate two examples, each comprising a plurality of multiplexed sensors S used without slaves wherein the subsequent image processing is made easier by arranging the sensors in symmetric grids.

Figure 12 illustrates the effect on the field surrounding each sensor in a matrix 50 caused by the approach through air of a curved object 35 with a high dielectric.

Figure 13 shows a circuit to improve the buffering of the multiplexer (MUX1, MUX2) power supply rails (P) (G), so that the substrate capacitance of the switch to the rails is reduced. The more accurately voltage follower 87 can achieve a 1:1 input:output ratio the lower the effective capacitance between each switch input and the substrate and the common pin to substrate becomes. The ratio approaches 1:1 if the output impedance of the voltage follower is much smaller than any impedance being driven to an effective AC ground. Where the variations in input capacitance causes a change in oscillator frequency the voltage follower must be capable of working at much higher frequencies than the

oscillator. This also means that the output impedance of the voltage follower must be as low as possible to drive any stray capacitance. Unfortunately voltage followers generally trade off accuracy of input:output ratio against low output impedance which means that a compromise has to be made.

A circuit configuration using a second voltage follower 86 is shown which avoids the need for this compromise. The configuration allows a very high accuracy voltage follower 87 to be used in the first stage because it only has to drive a large impedance created by the second, lower accuracy, voltage follower 86 which has a low output impedance. This configuration is hereafter referred to as 'double buffering'.

For example the first stage voltage follower 87 might follow its input to an accuracy of one part in a thousand and the second stage 86 to one part in a hundred. To supply 5V power to the multiplexers, two resisters 84 and 85 in series are connected between 5V and the VDD pin. The resistor 84 connected to 5V has its other pin driven by a capacitor 83 to the second stage voltage follower 86. This makes the resistor 85 to the VDD pin appear approximately one hundred times larger at the VDD pin. The VDD pin is then driven by the first stage voltage follower 87 through a capacitor 82. The first stage voltage follower 87 is thus not significantly degraded since it is driving a large impedance. The same technique is applied to the Ov rail.

If the second stage voltage follower 86 has a bipolar input it will generally have an output impedance dependent on its input impedance given by approximately 1/current gain. Thus if the second stage voltage follower 86 is driven by the output impedance of the first stage voltage follower 87, the second stage voltage follower's output impedance

will be very small (1/current gain of first stage) so it also will not be seriously degraded by driving a resistor connected directly to the rails.

Alternatively the resistors 84 can be replaced with a constant current source or the inputs of power supplies which are made to follow and supply the rails of the multiplexer can be double buffered.

For a bandpass action the resistors 84 and 85 can be replaced with tuned circuits supplying the rails of the multiplexers. This is an effective way of cutting out input noise of a different frequency as it sees a large capacitance to the substrate in the multiplexers that is not buffered out.

The two voltage followers 87 and 86 can be either driven from the same input or one can drive the other as shown in the diagram.

This buffering technique can be extended to triple and higher orders of application to improve the buffer amplifiers in terms of follower action at higher frequencies and of reducing output impedance.

Figure 14 shows another method of improving the multiplexer action by reducing the effective co-capacitance C across each switch. An additional impedance C2 approximately one thousandth of the value of said co-capacitance is added from each sensor pad p1 to a voltage follower 7. This reduces unwanted feedthrough of capacitance from an unselected pad to the common via the co-capacitance C3. In general an unselected sensor will add a capacitance C1 to the common whose value will be in series with the co-capacitance C3. The co-capacitance C3 is approximately 0.2pF. However with an almost 1:1 follower amplifier

driving one pin of an additional capacitor C2 and the other pin connected to the sensor the equivalent capacitance of the unselected pad on the input of the voltage follower is

$$C_{equiv} = \frac{C_1 C_3}{C_1 + C_2 + C_3}$$

If the additional capacitance C_2 is large with respect to the co-capacitance C_3, the unselected pad capacitance to the external world C3 is reduced by $\frac{C_1 C_3}{C_2}$.

In effect the additional impedance C2 forms a voltage divider with the impedance of a signal source driving a sensor pad, thus making the impedance of the 'off' switch greater. A tuned impedance at this point maximises the effect.

Figure 15 illustrates a technique whereby sensor plates pl can be used with individual back plates 90 which are switchable via a multiplexer MUX3 either to the voltage follower 7, making them into shield plates, or to signals in other phases via mux lines 92 thus making them into slaves. This can result in an imaging system capable of taking very complex readings but taking up minimal space. The back plates are typically each driven by a second simple voltage follower 91. Typically the sensor plate pl will be significantly smaller than the back plate 90, thus allowing co-capacitance reduction by the method described in Fig. 14.

Figure 16 shows a rectangular array of sensors characterising an object where the level of response from each sensor is displayed as a degree of shading. A characteristic pattern such as this may represent:

(i) the shape of an object (stronger response given by closer proximity at that point);

(ii) the pressure profile of an object (where a compressive membrane of some sort, such as expanded silicon rubber, is placed above the sensor array and optionally made conductive on the top surface then the proximity of the top surface to the sensor is proportional to pressure and affects the sensor response);

(iii) the internal construction of an object (if the dielectric varies - areas of lower sensor response may indicate voids in a moulding for instance, or areas of higher response may indicate un-cured areas in an adhesive).

The embodiments shown in Figs. 17 to 19 are intended for use as coin/token sensors.

The embodiment in Fig. 17 uses only the short and medium range effects for sensing the diameter, surface area, roughness, and thickness of a coin or token. It also detects the presence of a following second coin near or touching the first coin. This technique allows tokens to be used that are non-metallic. It consists of a partially enclosed buffered box with a "thickness" slave pad opposite the sensor on a parallel plate with the back sides of both plates buffered, as shown in Figure 2.

The arrangement of sensor and primary slaves is shown in Figure 17. The arc-shaped slave pads 3a, 3b, 3c are approximately the diameters of the various coins to be identified. They are tracked with fine lines to a ribbon cable 11 in which every alternate wire is connected to the buffer point (B), which may also exist as fine tracks between the slave pads on the PCB. A through-plated hole 20 leads to

tracking on the buffer plane 5.

Slave pad 3d is a second coin detector. If a second coin is touching (or nearly touching) the first coin, its presence will be detected when slave pad 3d is switched on. When this happens a strong effect will be coupled to the second coin and on through the first coin to the sensor. Slave pad 3e and its associated ground plate show the long range effect, but isolated to the region confined between the two parallel buffer plates formed from the backs of the plate containing the sensor and the opposing parallel plate containing the thickness slave pad (equivalent to the "buffered box" in Figure 2). The slave pad 3e can be made to have an adjustable "superground" effect by driving it with a variable out of phase voltage.

In the embodiment of Figure 18, the sensor pad and slave pads are made optimally in a particular shape such that on the side of mechanical coin stop 12 the minimum intersection of the smallest and largest coin is used - i.e. an arc that fits the largest coin 34. The shape of the sensor arc away from the stop is indirectly determined by the smallest coin that is to be identified as this will determine the arc of slave pad 3a.

For surface area sensing, all slave pads are turned off except for the outer one which lies outside the diameter of the coin/token. Thus field lines radiate from anywhere on the surface of the token. The frequency of the oscillator is decreased in proportion to this surface area.

For a number of coins in a stack, either multiple sensors can be used in a row or, if the coins are stationary and physically touching, a row of slave pads can be turned on. For example, if they are turned on in phase they will couple through coins sitting above them and through other

coins, eventually to a coin above the sensor. The slave pad determining coin thickness locates coins at a distance from the sensor with an analogue effect. Several slave pads can be used to increase precision.

The information received by switching the slave pads on and off and in and out of phase is seen as an effect on the sensor plate. Normally for low cost construction this is in the form of a frequency derived from a Schmitt trigger oscillator 15 (Figure 3) which has a low capacitance input, low impedance output buffer 7 before the Schmitt trigger 6.

The frequency obtained when each slave pad is switched on in turn (in or out of phase) is measured, and may be stored. The pattern of frequencies thus observed characterises a coin or other object. The pattern may incorporate frequencies derived when slave pads to one side are switched on (a good measure of diameter) and/or those opposite (a good measure of thickness). A comparison with previously stored values or limits can be made by algorithms ranging from complex pattern matching to simple thresholding (which determines which slave pads are overlapped). This comparison can then be used to make accept/reject decisions. Identification without the "thickness" slave pad may be advantageous in that it allows identification to be performed simply by placing the coin/token onto a flat detector.

If the coin is identified in motion rather than when against the gate then the slave pads are shaped as in Figure 19 to attain a matched filter. If more than one coin is allowed to stack behind the gate then the slave pads should be shaped as in Figure 18. The reason being that the second coin should not be allowed to overlap the slave pads (3a-3c) which mainly measure diameter.

Figure 20 shows graphically a simplified statistical output of the coin discriminator embodiment shown in figures 17, 18 and 19. Each horizontal axis 51 in the diagram represents the frequency measured at the sensor with a particular slave turned on. Each normal curve 52 represents the measured frequencies of a large number of samples of a particular type of coin with the same slave turned on. Each type of coin can therefore be characterised as shown by the combination of frequency responses from all the slaves. The 'accept window' (i.e. allowable frequency deviation from the mean) can be set from the width of the normal curve and the desired percentage of correct coins rejected vs fake coins accepted.

Referring now to Figure 21, there is shown an embodiment suitable for chemical dielectric measurement (of one or many containers). This embodiment consists of a plurality of sensor devices 37, each comprising sensor pads (S), buffer areas (B), and slave pads (F) and being positioned optimally for the effect that it is desired to sense. The chemical 38 to be tested may overlay one or more of the sensor devices 37. If multiple sensors, buffers or slave pads are in close proximity to the same container, differences in density and dielectric can be measured in different places in the container.

Figure 22 shows another embodiment for chemical dielectric measurement, which has a cylindrical slave pad F forcing the field lines to cross most of the chemical 38 to be tested. Other arrangements with different geometries of sensors, buffers and slaves attached to a container for containing the chemical to be tested may alternatively be utilised.

Figure 23 shows the circuit schematic for an amplitude-modulated version of sensor and slave arrangements de-

scribed previously. If slave members (F) are being used they are connected, via a multiplexer if necessary, to a fixed frequency oscillator 68 and a voltage amplifier 69 via a resistive, capacitive, or inductive coupling 70. The oscillator 68 may be locked by the use of a crystal, for instance. The sensor (S) is connected (possibly via a multiplexer) to the voltage follower 7 as before, and then to an amplifier 62. The amplified signal is then passed through a narrow band-pass filter 63 (e.g. 455 KHz ceramic) and amplified again by amplifier 64. The signal is then rectified 65 by one of several means e.g. half wave, full wave, PLL quadrature demodulation or a multiplier driven by oscillator 68 and appropriate phase shift. Finally an op-amp 67 is used to give a high-gain output. As before, the slave (F) couples to the sensor (S) capacitively through the environment. If the arrangement is used as an array of multiplexed sensors without slaves then the oscillator 68 is connected directly to the sensor (S) via a resistive, capacitive, or inductive coupling 70 and a direct link 71.

Figure 24 shows a technique for enhancing internal imaging, particularly for impedance tomography, whether it be mechanical or electrical impedance. The description follows for mechanical impedance. If an object 73 is suspended in a medium 72 of similar, but not identical, dielectric constant a capacitive sensor array 74 will be unable to image the object if it is static. If, however, a modulation source 75, such as a loudspeaker, is used then the object 73 can be made to vibrate or resonate within the medium 72. The use of a correlation detector 76 will than allow the object to be picked out of the surrounding medium by virtue of its movement. The object and the medium must be significantly mechanically dissimilar, particularly in their rigidity, for this to work. The same technique will work for to objects with different electrical impedances but similar dielectric constant if the modulating source 75

provides an oscillating magnetic field. Similarly a single pulse or collapse of an external field whether electrostatic, magnetic, mechanical or optical can be used to distinguish an object from the medium or enhance its resolution.

Whilst particular embodiments of the present invention have been described, various modifications will be envisaged without departure from the scope of the invention as defined in the appended claims. For instance, the sensor, buffer and slave members may be any suitable shape according to the application in which the device is intended to be employed. For example, as shown in Figures 1 and 7, the sensor is square-shaped and the buffer and slave members have corresponding corners and straight sides. On the other hand, in Figures 14, 15 and 16 the sensor is circular and the buffer and slave pads are arcuate as described hereinabove. They may also be arranged in any suitable physical arrangements, such as in a plurality of shapes, for example parallel lines, in a zig-zag formation. In another example, a device in accordance with the present invention may be used for detecting objects through water by use of slave members to set up a potential gradient in the water to the sensor, which is disturbed by the advent of an object to be detected. In yet another example suitable for chemical dielectric testing in a container, the device may include a circular sensor and concentric buffer members and slave members driven in or out of phase with the sensor. The device is located inside the container with another sensor outside the container, thereby sensing the change in dielectric in vitro on one side of the inside sensor giving a gradient change from that sensor to the one located outside and thus positional information on density and composition of the chemical.

CLAIMS

1. A device for determining the presence and/or characteristics of an object (16) or a substance (38), said device comprising capacitive means (1,3a,3b,3c), the capacitance of which is changed due to the presence and/or characteristics of said object (16) or substance (38), and a circuit arrangement for detecting said change in capacitance, characterised in that said capacitive means (1,3a,3b,3c) comprises one or more sensors (1) and one or more slave members (3a,3b,3c) positioned relative to said sensor or sensors (1) and arranged to be driven in a predetermined phase relationship with respect thereto, such that the change in capacitance detected by said circuit arrangement (15) is influenced by electrostatic coupling between said one or more sensors (1) and said one or more slave members (3a,3b,3c).

2. A device as claimed in claim 1, wherein said capacitive means (1,3a,3b,3c) includes a plurality of sensors (1) and/or a plurality of slave members (3a,3b,3c), and said device includes one or more multiplexers (MUX1, MUX2) arranged to address the sensors and/or slave members sequentially or simultaneously.

3. A device as claimed in claim 2, wherein the power rails (P,G) of the or each multiplexer (MUX1, MUX2) are connected to buffering means (7,C1,C2) so as to inhibit internal capacitance to said rails (P,G) and effectively making emerging lines buffered.

4. A device as claimed in any preceding claim, wherein one or more buffering members (2,5) are positioned relative to the sensor or sensors (1) so as to enhance the sensitivity of the device and to shield the sensor or sensors (1) from unwanted external effects.

5. A device as claimed in any preceding claim, wherein the circuit arrangement (15) includes an oscillator (15) having an output frequency dependent on the change in

capacitance of said capacitance means (1,3a,3b,3c).

6. A device as claimed in any one of claims 1 to 4, wherein the circuit arrangement (15) includes an oscillator having an output amplitude dependent on the change in capacitance of said capacitive means.

7. A device as claimed in any preceding claim, including means for storing the output of said detecting circuit arrangement (15) in respect of the or each sensor (1) and the or each slave member (3a,3b,3c) when driven, such that said stored outputs can be used to determine the presence and/or characteristics of said object (16) or substance (38).

8. A device as claimed in any preceding claim, wherein the capacitive means (1,3a,3b,3c) are positioned on one surface which the object (16) is adjacent in order to determine its characteristics.

9. A device as claimed in claim 8, wherein additional capacitive means (17) are located on a second surface positioned on the side of the object (16) remote from said one surface.

10. A device as claimed in any preceding claim, wherein the capacitive means (1,3a,3b,3c) comprises one sensor (7) and a plurality of slave members (3A,3B,3C) arranged generally concentrically around said sensor (1), and includes one or more buffer members (2,5) arranged relative to the sensor (1).

11. A device as claimed in any preceding claim, including means (12) for retaining the object (16) in a stationary position whilst its characteristics are determined.

12. A device as claimed in any one of claims 1 to 10 wherein said capacitive means (1,3a,3b,3c) are arranged so as to determine the presence and/or characteristics of an object (16) as the object moves past said capacitive means.

13. A device as claimed in any preceding claim, wherein the one or more sensors (1) and one or more slave members (3a,3b,3c) are etched on one side of a double-sided PCB,

and an additional slave member is etched on a further double-sided PCB directly opposite said one or more sensors (1) so as to determine thickness of said object (16), outer faces of the two PCBs being connected to buffering means (7).

14. A device as claimed in any preceding claim for use in chemical dielectric testing, wherein an arrangement of one or more sensors (S), one or more slave members (F), and one or more buffer members (B) are located beneath, on the outer side or on the inside of one or more containers for containing the chemical to be tested.

15. A device for determining presence and/or characteristics of an object (16) or a substance (38), said device comprising capacitive means (p1-p4), the capacitance of which is changed due to the presence and/or characteristics of said object (16) or substance (38), and a circuit arrangement (15) for detecting said change in capacitance, characterised in that said capacitive means (p1-p4) includes a plurality of sensors (p1-p4) connected to the circuit arrangement (15) via one or more multiplexers (MUX1) the power rails (P,G) of which are connected to buffering means (7,C1,C2) so as to inhibit internal capacitance to said rails (P,G).

16. A device as claimed in claim 15, wherein the buffering means (7,C1,C2) includes a voltage follower (7) connected to the power rails (P,G) via capacitors (C1,C2).

17. A device as claimed in claim 18, wherein unaddressed lines and sensors (p1-p4) are connected to the voltage follower amplifier (7), thus inhibiting feedthrough capacitive effects in individual switches in the or each multiplexer and allowing long lines to the sensors in the same side of a PCB upon which the device is mounted.

18. A device as claimed in claim 15 or 16, wherein the output of the or each multiplexer (MUX1) is fed to the voltage follower (7) which has its power supply rails driven by a later stage low output impedance voltage fol-

lower.

19. A device as claimed in claim 16, 17 or 18, wherein said voltage follower amplifier (7) includes a dual-gate Mosfet Q, gate 2 of which is buffered for optimal elimination of input capacitance.

20. A device as claimed in any one of claims 16 to 19, wherein an additional impedance (C2) is connected between each sensor (p1-p4) and the output of said voltage follower (7) so as to reduce the feedthrough effect of external capacitance on selected sensors via the co-capacitance of a switch of said or one said multiplexers which is turned off.

21. A device as claimed in claim 15, wherein the buffering means includes two voltage followers (87,86) connected in series, one being designed particularly for high precision and the other for low output impedance.

22. A device as claimed in any one of claims 16 to 21, wherein the power rails (P,G) of said one or more multiplexers (MUX1) are connected to constant current sources and are driven by a capacitor to the output of said voltage follower (7).

23. A device as claimed in any one of claims 15 to 22, wherein said plurality of sensors (p1-p4) is provided with back plates which may be switched to be slave members or shield plates.

24. A device as claimed in any preceding claim, wherein the one or more sensors (1) and one or more slave members (3a,3b,3c), if used, are etched on one side of a PCB.

25. A device as claimed in any one of claims 15 to 25, wherein one or more additional components of the device are connected to said buffering means (7,C1,C2), so as to allow all components of the device, including the sensors (p1-p4), to be located on one side of a PCB without the use of through-holes.

26. A device as claimed in any preceding claim, including means (15) for measuring the effective charge rate or

loss tangent from the or each sensor.

27. A device as claimed in any one of claims 16 to 26, wherein buffering members connected to said voltage follower (7) are located behind the sensors (p4-p4) and/or said one or more multiplexers (MUX1) and/or a first stage of said voltage follower.

28. A device as claimed in any one of claims 15 to 27, wherein the output of said buffer/follower amplifier (7) is connected to a Schmitt trigger (6), and circuit means (19) are provided between said amplifier (7) and said Schmitt trigger (6) to vary the hysteresis level of said Schmitt trigger (6).

29. A device for determining the presence and/or characteristics of an object (16) or a substance (38), said device comprising capacitive means (1,3a,3b,3c), the capacitance of which is changed due to the presence and/or characteristics of said object (16) or substance (38), and a circuit arrangement (62-70) for detecting said change in capacitance, characterised in that said circuit arrangement (62-70) includes a fixed frequency oscillator (68), the amplitude, output and/or phase of which is dependent on said change in capacitance.

Figure 1

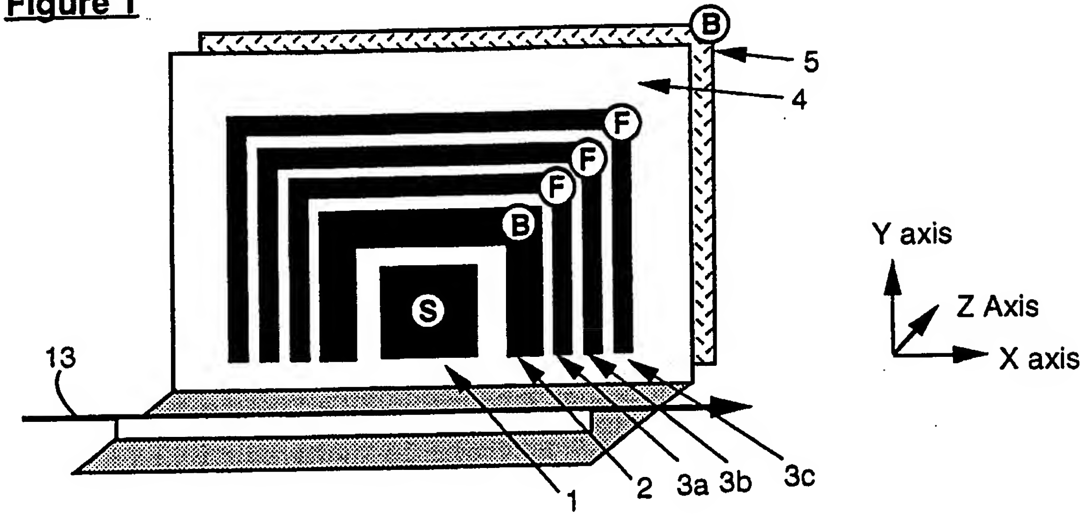


Figure 2

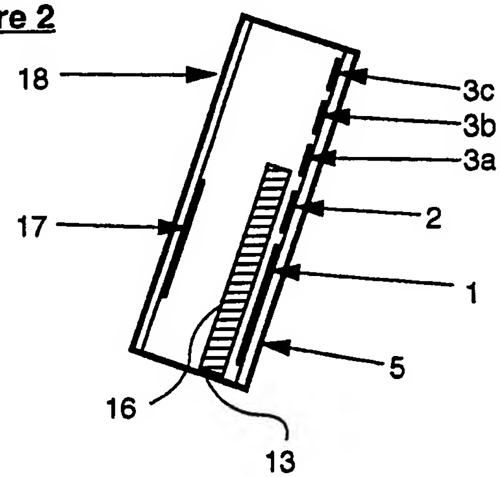


Figure 3

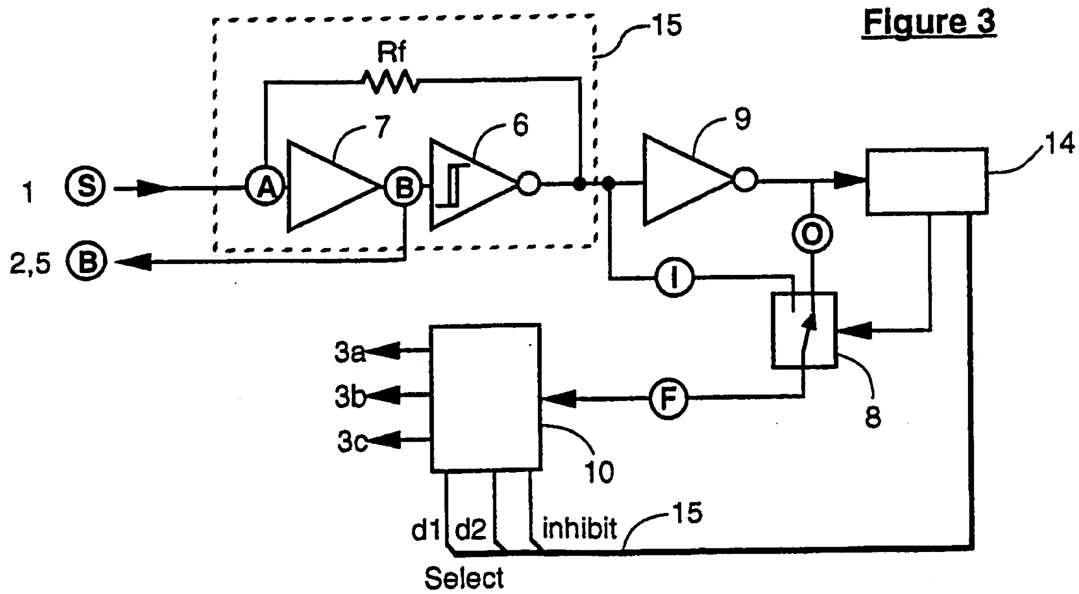


Figure 4

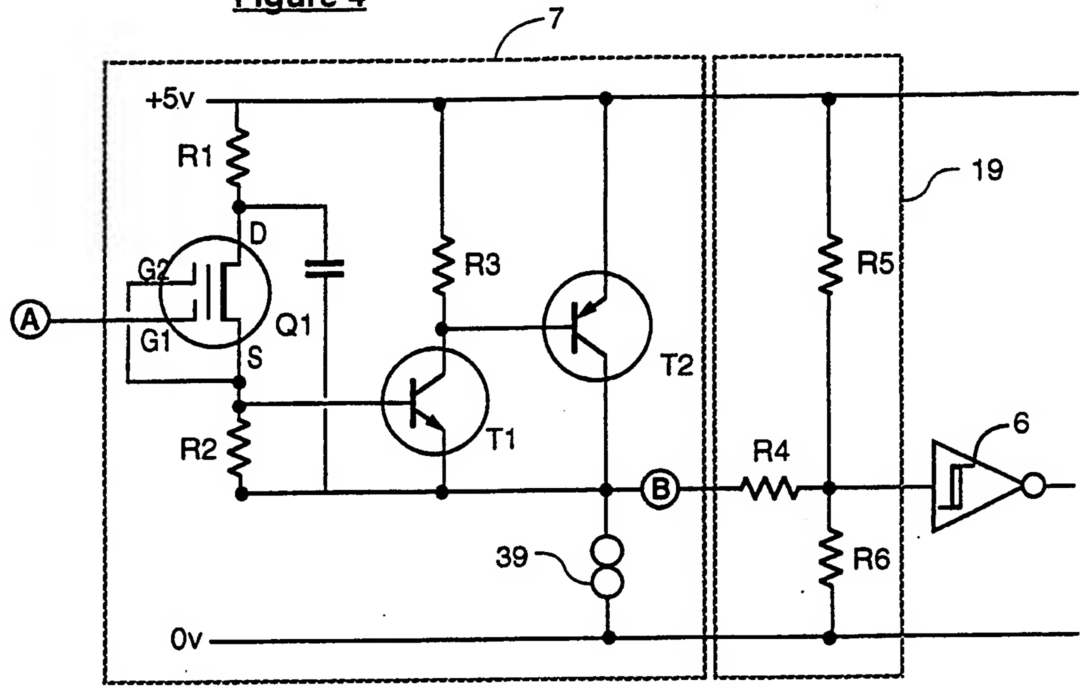


Figure 5

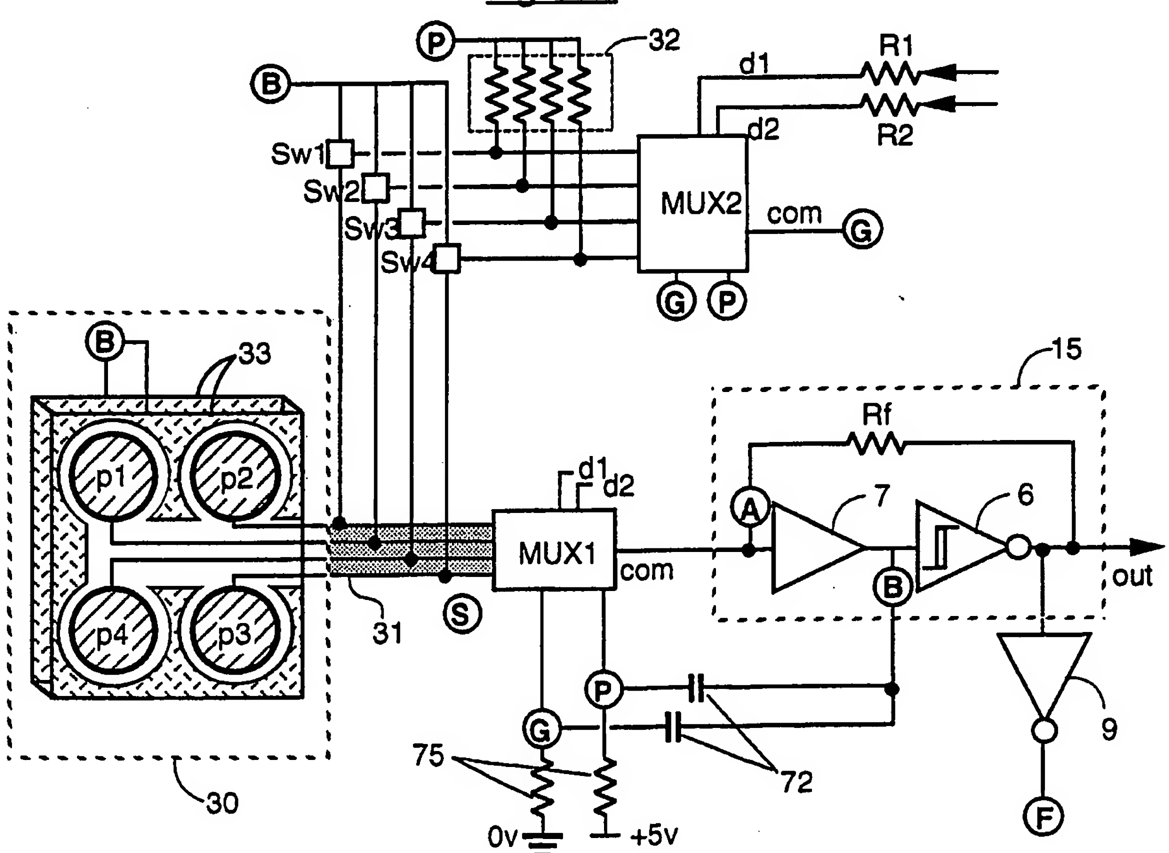


Figure 6

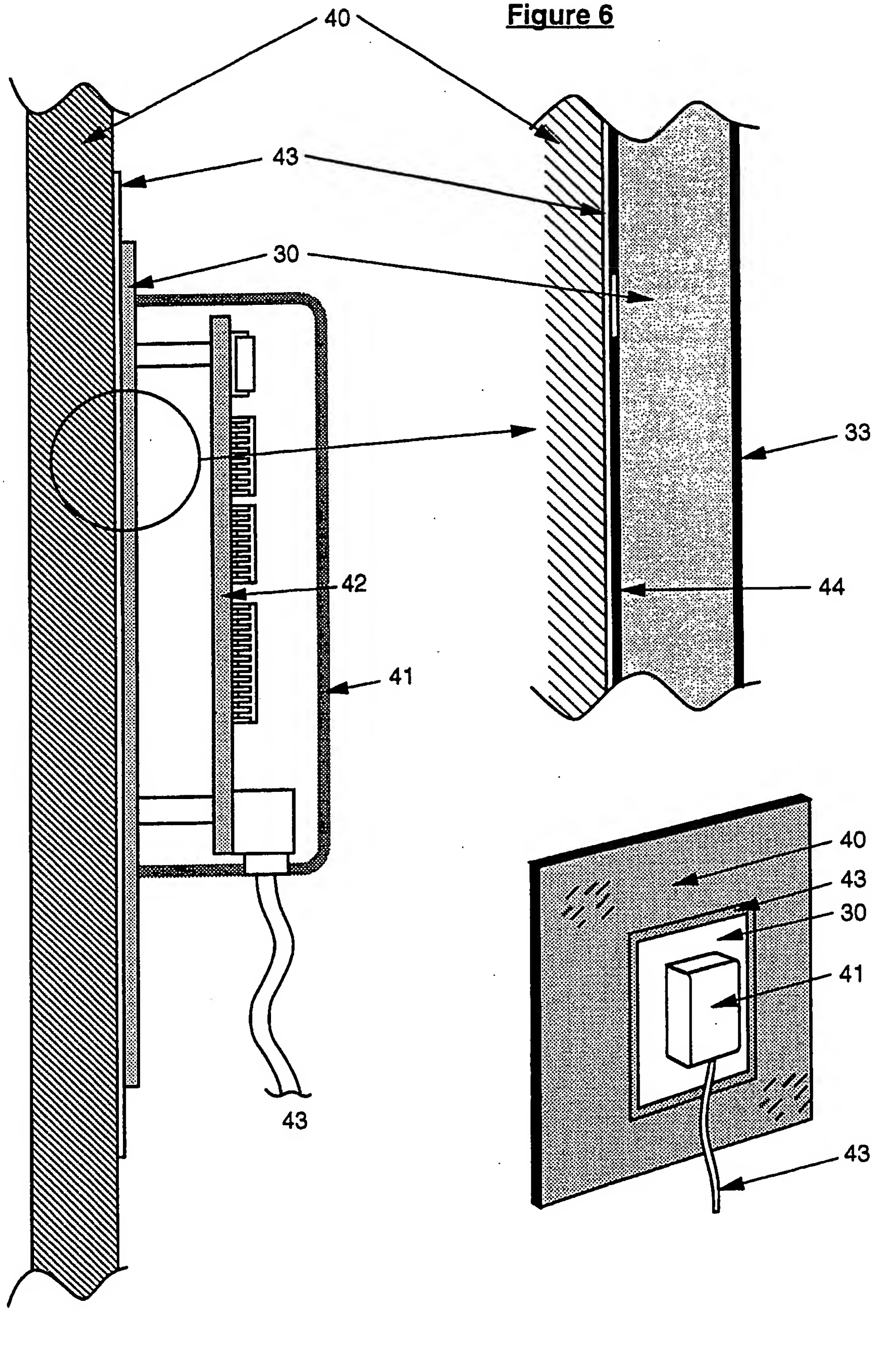


Figure 7a

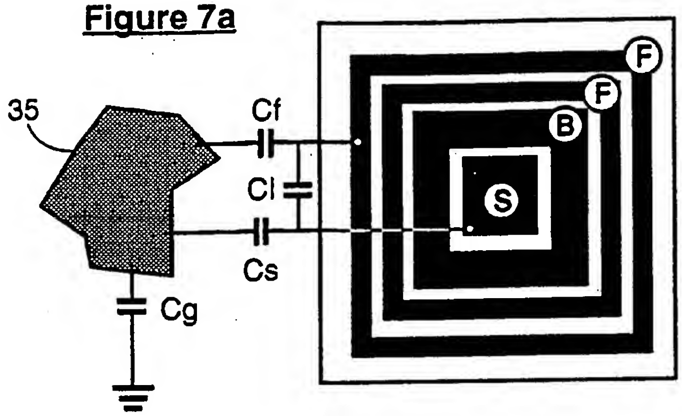


Figure 7b

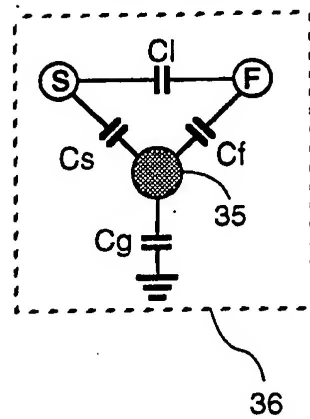
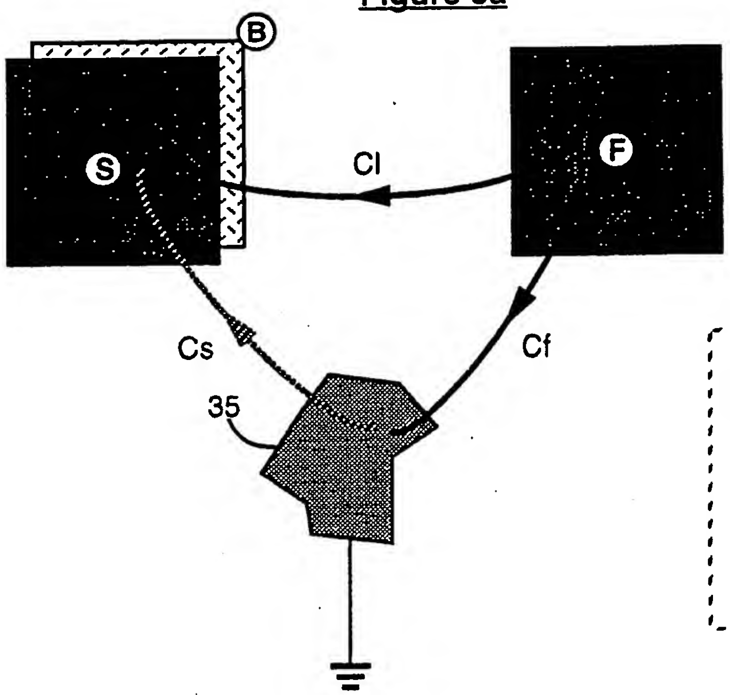


Figure 8a



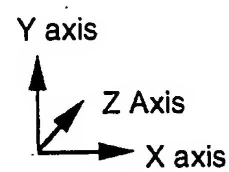


Figure 8b

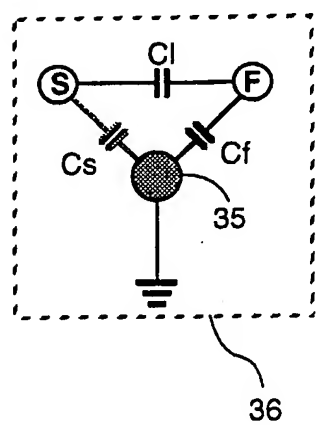


Figure 9

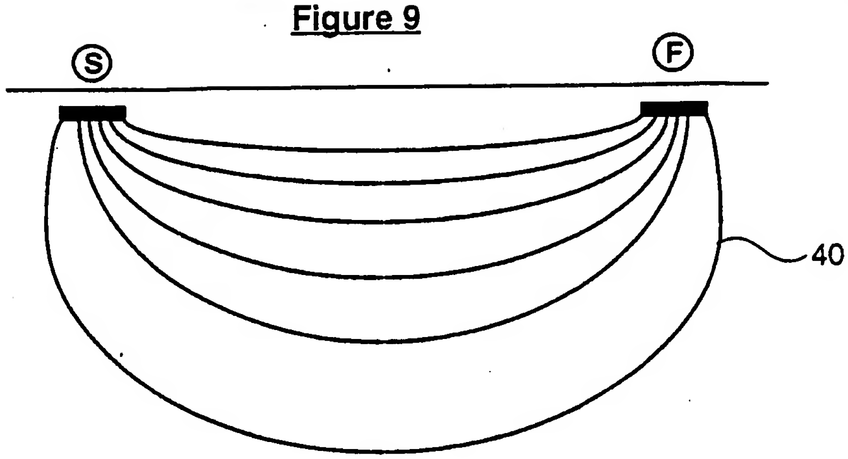


Figure 10

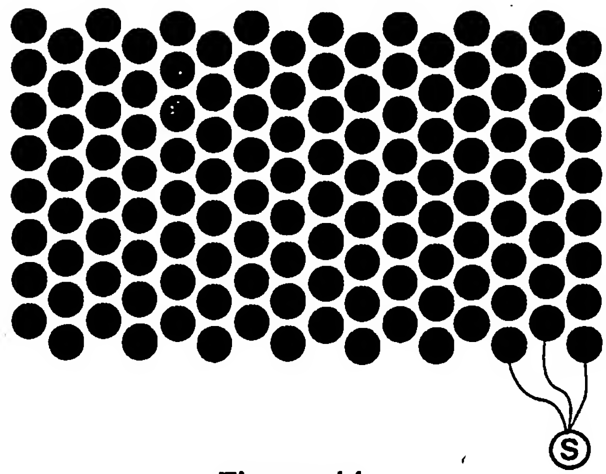


Figure 11

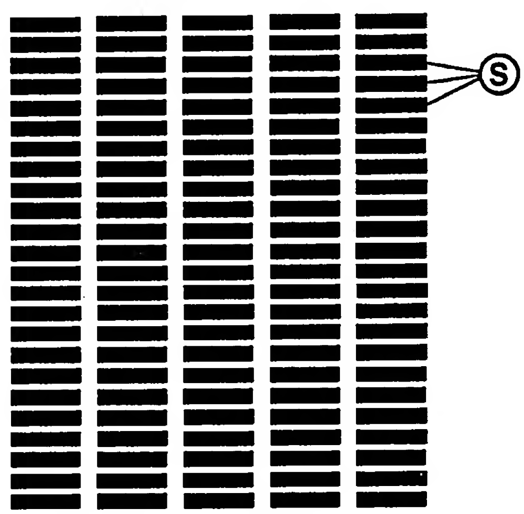


Figure 12

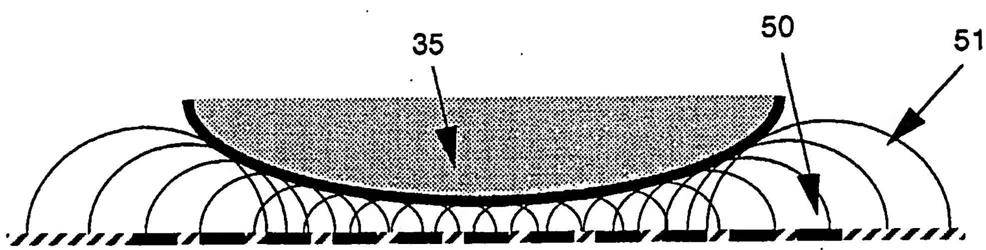


Figure 13

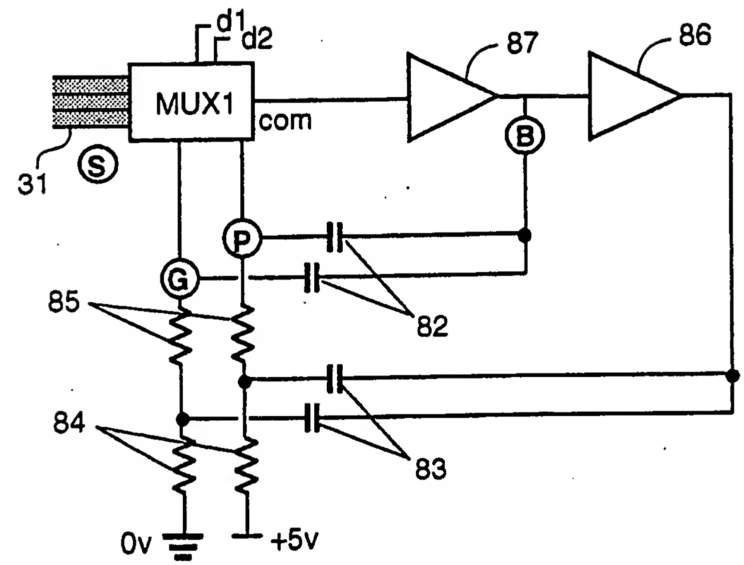


Figure 14

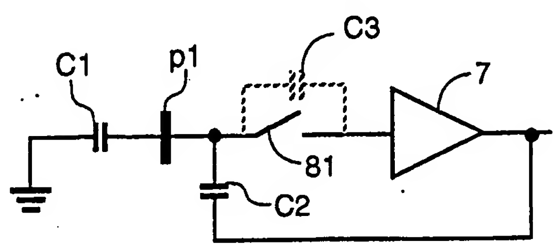


Figure 15

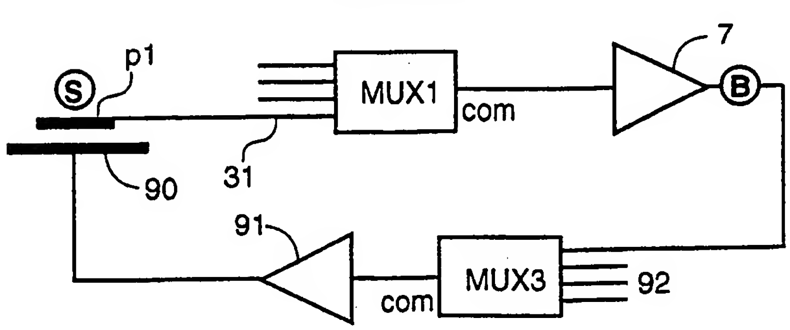


Figure 16

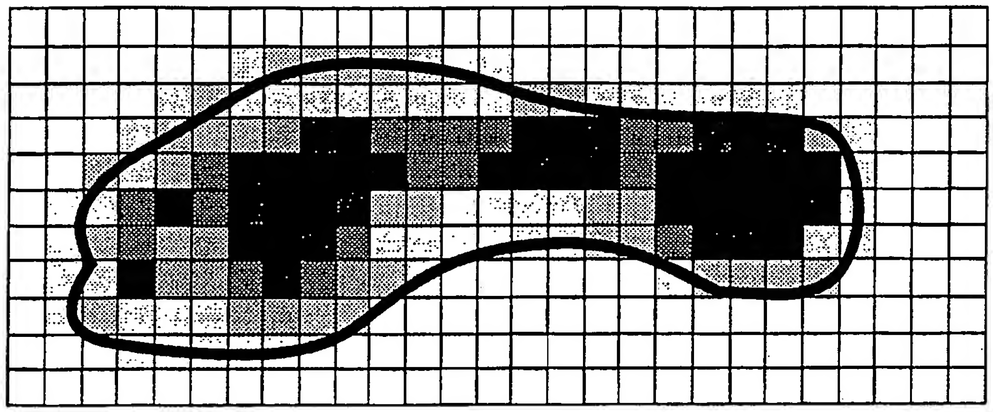


Figure 17

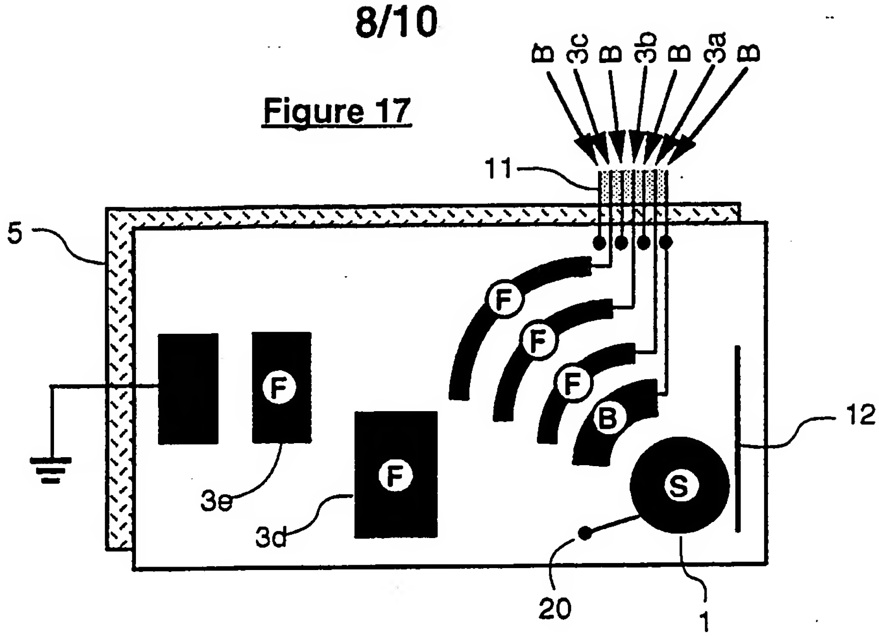


Figure 18

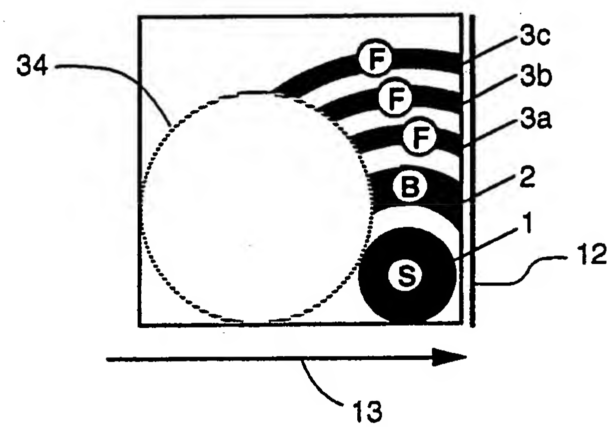


Figure 19

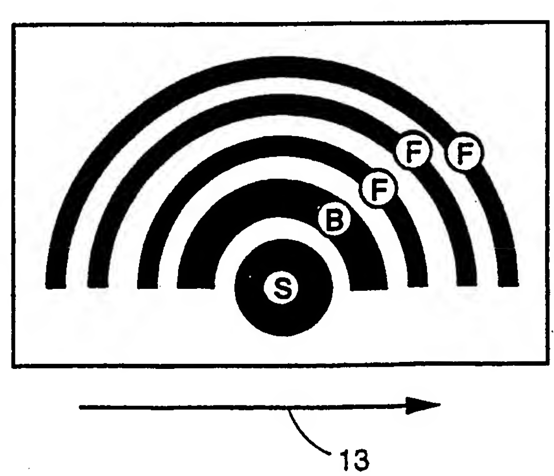


Figure 20

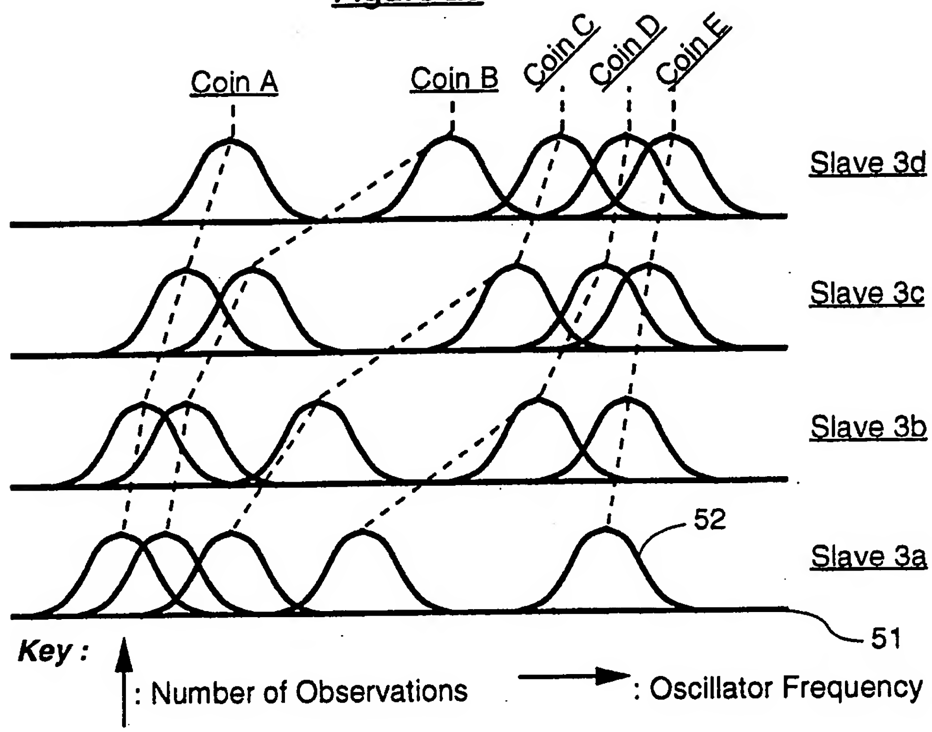


Figure 21

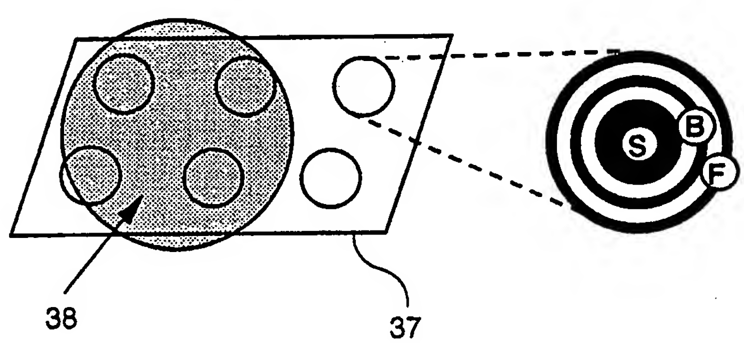


Figure 22

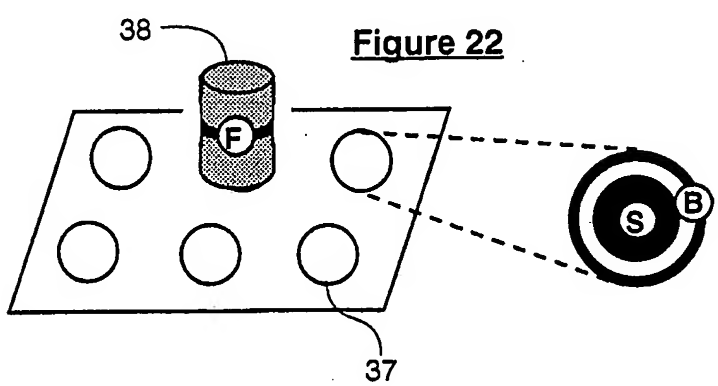


Figure 23

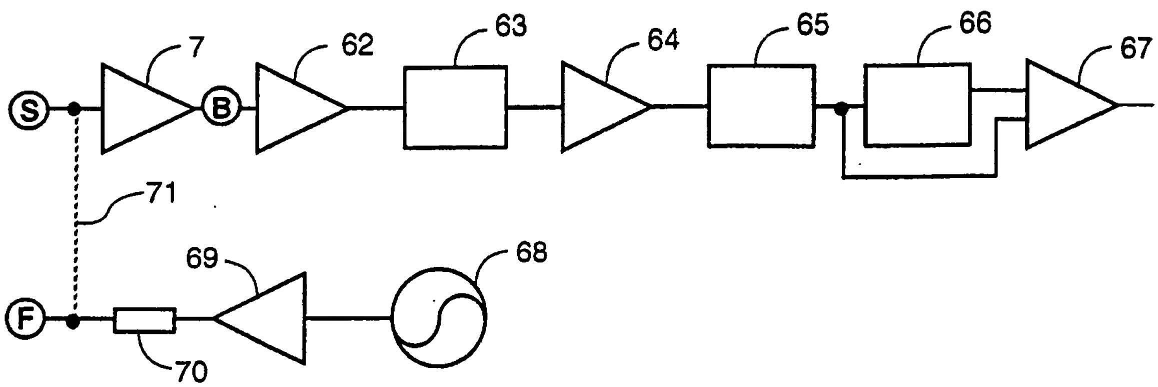
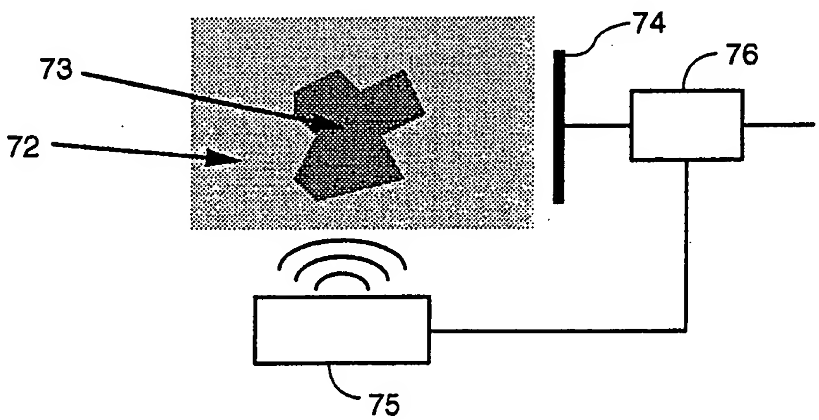


Figure 24



INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 91/02021

I. CLASSIFICATION OF SUBJECT MATTER (If several classification symbols apply, indicate all)[6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int.Cl. 5 G01B7/34; G01B7/28

II. FIELDS SEARCHED

Minimum Documentation Searched[7]

Classification System	Classification Symbols
Int.Cl. 5	G01B

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched[8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT[9]

Category°	Citation of Document,[11] with indication, where appropriate, of the relevant passages[12]	Relevant to Claim No.[13]
X,P	EP,A,0 425 823 (R.G.DOWER) 8 May 1991	1-4, 6-12, 14-19, 22,27,29
	see column 1 - column 11, line 34 see column 14, line 50 - column 20, line 4; claims 1-12; figures	
A		13,20, 21-26,28

A	EP,A,0 004 757 (GOULD INC) 17 October 1979 see the whole document ---	1-29
A	WO,A,8 801 747 (L.J.ROADES ET AL) 10 March 1988 see the whole document ---	1-29

° Special categories of cited documents :[10]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
25 FEBRUARY 1992	05 MAR 1992
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	BROCK T.J.

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ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO. GB 9102021 SA 53306

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on
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Patent document cited in search report	Publication date	Patent family member(s)		Publication date
EP-A-0425823	08-05-91	None		
EP-A-0004757	17-10-79	US-A-	4190797	26-02-80
		CA-A-	1138113	21-12-82
		DE-A-	2952825	04-09-80
		FR-A,B	2454084	07-11-80
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		EP-A-	0281610	14-09-88
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		US-A-	4908574	13-03-90

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82